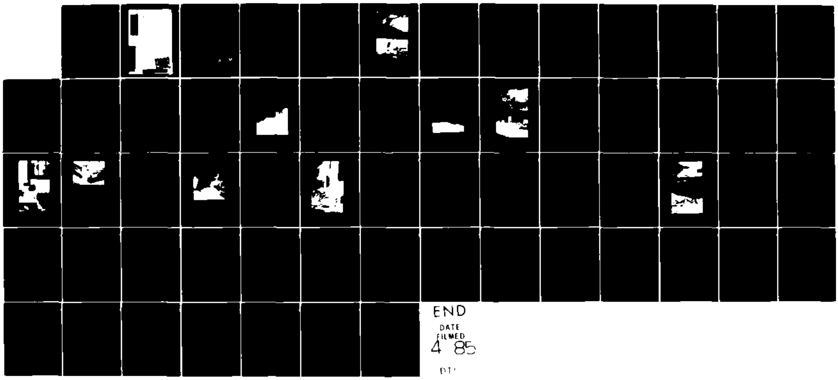
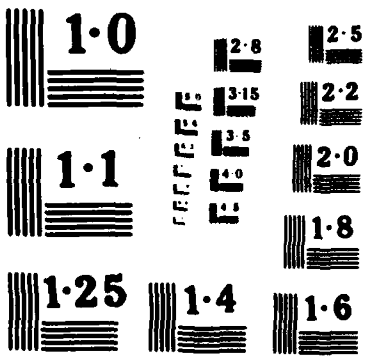
AD A150 746 NATURAL HAZARDS AND RESEARCH NEEDS IN COASTAL AND OCEAN 1/
ENGINEERING SUMMA..(U) NATIONAL SCIENCE FOUNDATION
WASHINGTON DC J H NATH ET AL. NOV 84

UNCLASSIFIED F/G 13/2 NL



END
DATE
FILMED
4 85
DTIC


1.0
2.8
2.5
3.15
2.2
3.5
1.1
2.0
4.0
1.8
1.25
1.4
1.6

Natural Hazards and Research Needs in Coastal and Ocean Engineering

Summary and Recommendations to the National Science Foundation and the Office of Naval Research

by the Ad Hoc Committee
for the Civil and Environmental Engineering Division
National Science Foundation

Natural Hazards and Research Needs in Coastal and Ocean Engineering

Summary and Recommendations to the
National Science Foundation
and the
Office of Naval Research

Natural Hazards and Research Needs in Coastal and Ocean Engineering

Summary and Recommendations to the National Science Foundation and the Office of Naval Research

by the Ad Hoc Committee
for the Civil and Environmental Engineering Division
National Science Foundation

Editors
John H. Nath, Professor
Oregon State University

and

Robert G. Dean, Professor
University of Florida

November 1984

Contents

Fig. 1. *Before Hurricane Eloise hit the Gulf of Mexico coast of Florida in September 1975, this section of heavy sea wall in Bay County provided seemingly strong protection against storm surge tide and strong waves. Note the end triangle of the gable house in the upper left part of the photograph.*

Fig. 2. *After Hurricane Eloise of 1975, along the same section of Bay County as shown in Figure 1. The same house as indicated in Figure 1 is shown by the arrow. The heavy sea wall and several of the houses have been completely demolished as a result of large storm tides and high waves.*

Preface

Hawaii, Alaska, and 21 of the 48 contiguous states have shorelines on the Pacific, Arctic, and Atlantic Oceans, the Bering and Beaufort Seas, and the Gulf of Mexico. Eight states border the Great Lakes (New York also borders the Atlantic Ocean). Thus, 30 of our 50 states, plus Puerto Rico, the Virgin Islands, Guam, and other protectorates, have coastlines. It is estimated that roughly one-half of the population of the United States lives within 50 miles of a coast. Therefore, the safety and economics of structures on the coast and in the ocean are of major importance to the United States.

The forces from waves, currents, wind, ice, and human activities are continuously reshaping the shoreline and changing the ecological equilibrium of the coast. Offshore on the continental shelf are thousands of platforms supported by the ocean bottom. Anchored in the deep ocean are structures of various sizes, from small buoys to large ocean vessels. Environmental forces and how they are accommodated through engineering design determine the safety and economic viability of these structures. Harbors link our land transportation terminals to vital overseas trade routes. Consequently, they must be designed properly to resist natural hazards, and they must be economically competitive in world markets.

Engineers have designed well in most cases, but some coastal and ocean systems have failed, and some may have been designed too conservatively. Failures of both kind demonstrate that engineering research is needed to understand better the characteristics of hazards and the physical systems that resist them. As new challenges appear, there must be a well-educated cadre of engineers to develop effective solutions.

On February 14 and 15, 1984, an ad hoc committee of invited engineers met at Oregon State University to explore the research needed on natural marine hazards. The workshop was supported by the National Science Foundation and the Office of Naval Research through grant no. CEE-8320314 to Oregon State University. The committee comprised 26 eminent engineers who have

devoted most of their careers to working on coastal and ocean problems. They came predominantly from universities, although three were from federal agencies and one was associated with a consulting engineering firm. Alaska, Hawaii, Colorado, Washington, D.C., and 12 of the 48 contiguous states with shorelines were represented. The participants energetically discussed the hazards to which coastal and ocean structures, beaches, and disposal systems are subjected, the research needed to understand these hazards, and the necessity for further development of university graduate programs for this subject. This report is a summary of the workshop findings.

The committee reached a consensus that the United States would benefit from a national focus on coastal and ocean engineering research in its universities. A very large area of the country is subjected to the effects of hurricanes, winter storms, possible long-term sea level rise, tsunamis, the disposal of heat, organics, and chemicals in the ocean, and other natural and man-made hazards. Carefully directed research programs can help to mitigate these hazards and reduce the loss of life and property.

Research needs in this area are significant. This report presents a first estimate of what research is needed. The committee is aware that many subjects presented here are under investigation to some extent by government agencies and by relatively small university research efforts. The recommendations presented are intended to supplement these programs, not supplant them. For example, an emphasis is placed on the need for an investigative team to report on the effects of severe events on the coasts and in the oceans, in conjunction with measurements, to gather much needed additional information on the characteristics of natural hazards. The Committee on Natural Hazards of the National Research Council at present performs a similar function. However, the committee must respond to *all types* of disasters, on land and sea, and budget limitations preclude surveys of most of the severe coastal and offshore events.

In the time available to the ad hoc committee, all existing organizations that could be touched by the recommendations herein could not be identified. Thus, this report represents a first attempt to identify those coastal and ocean hazards that can be mitigated by federal support of engineering research in U.S. universities. Coordinating such research with on-going efforts is left to the future.

Coastal and ocean engineering is a highly technical and diverse subject. However, it is our intent that this report be readily understood by persons with nontechnical backgrounds. In a lim-

ited space, it is not possible to address all the problems that exist, but the important issues presented here indicate the breadth of the committee's concerns. It is hoped this report will serve as a preliminary planning document.

The primary recommendation of the committee is that the Civil and Environmental Engineering Division of the Engineering Directorate of the National Science Foundation establish a program of coastal and ocean engineering research with a funding base building to $10 million per year within three years from the program initiation.

John H. Nath, Chairman
Ad Hoc Committee for a Workshop on
Natural Hazards: Research Needs
in Coastal and Ocean Engineering

Executive Summary

Winter storms, hurricanes, tsunamis, submarine mudslides, the thrust of ice packs, corrosion, and other marine hazards have caused heavy loss of life and property on the coasts of the United States and at sea. Annual losses have increased rapidly since World War II, partly because of the accelerated population growth in the coastal regions and partly because of increased property values there. Some coastal engineering problems are exacerbated by domestic, industrial, and agricultural waste disposal, the volume of which grows out of proportion with the population growth.

University research in coastal and ocean engineering has been funded piecemeal by federal and state agencies for the past five decades. The work has been important for developing basic knowledge of the characteristics of natural hazards and of ways to plan for them in terms of building appropriate structures and regulating human activities. However, research funds have diminished severely in the last decade, while losses to the nation have increased from hurricanes, winter storms, ocean waste disposal, and other hazards. The nation must reverse this trend and give more attention to hazard mitigation through university engineering research and graduate education. The effort will help provide economical solutions, ensuring maximum public safety within fiscal and other constraints.

Even under ordinary storm conditions there is at least some economic loss because the quality of our coastal structures and harbors varies widely. Under extraordinary conditions with particularly severe events like Hurricane Frederic in 1979, losses run into billions of dollars. Economic losses result from a variety of factors: flooding of coastal areas, beach erosion, harbor siltation, excessive wave forces on structures, breakwater failures, capsizing of fishing and recreational boats, broken moorings for aids to navigation, ice forces and other cold weather problems, metal corrosion and collapse, accumulations of marine growths impairing operations, loss of timber strength from marine borers, and pipeline displacements from submarine mudflows. The list is not exhaustive, but it provides an idea of the range of problems that concern coastal and ocean engineers.

Coastal and Ocean Hazards

The ad hoc committee on natural hazards and research needs, supported by the National Science Foundation and the Office of Naval Research, identified the following hazards as the most important ones and cautioned that they require engineering research now.

Winter Storms

The winter storms of 1982-1983 resulted in extensive economic losses all along the west coast. In California alone nearly $100 million in damage to public property occurred (2).* Normally about four to six major storms strike the California coast each winter. However, there were seven in 1982 and eight in 1983, all of which were unusually intense. The paths of Pacific Ocean storms approaching the west coast of the U.S. were more due west-east than usual. This meant that the wind transferred its energy to the water over longer distances, resulting in much stronger, more dangerous waves. The combined effects from stronger waves, extreme lunar tides, wind-induced storm surge, and an increase in the general sea level of about 1 foot (apparently caused by El Niño) destroyed pier decks and pilings, scoured sediment around piles and under seawall foundations, and produced wave overtopping of breakwaters and seawalls.

Future losses of this nature can be greatly reduced if pilings are stronger and driven deeper into the foundation materials; if pier decks are built higher above the mean sea level; if higher breakwaters are designed using heavier and stronger armor units; if seawall foundations are more extensive; and if local or state planning agencies provide more prudent guidance or regulations for siting and constructing coastal structures and facilities.

Obviously, these remedies are expensive, but a well-educated coastal engineer can make decisions that are economically sound. For example, it is the engineer's responsibility to determine how high the breakwater must be. Breakwaters are much wider at the bottom than at the top because the side slopes must be maintained. Therefore, construction costs rise rapidly with increasing breakwater height: the higher the breakwater, the broader must be the base which supports it. Additional heights are achieved by adding material all across the bottom of the breakwater. If the breakwater is constructed higher than required to prevent overtopping, resources have been wasted. If it is too low, the safety of the public is at risk. If an engineer were better able to predict the

* Numbers in parentheses refer to the references.

combined effects of severe events, such as those that occurred on the west coast in the winter of 1983, he could design structures that are both safe and economical. We need to know more about the selection of designs which work best in storm conditions, more about the resulting wind, wave, and current forces on coastal and ocean structures, and more about structural resistance to environmental forces.

Hurricanes

Hurricanes originate in the tropics during warm summer months and intensify by extracting tremendous energy from the warm ocean surface water. They produce sustained winds of 120 mph or more with gusts of around 180 mph. The wind, combined with high storm tides and large waves, destroys lives on land and at sea and devastates property. A negative pressure within the storm causes the water level to rise higher than the level outside the storm. In addition, the wind acts with a shearing force on the surface of the water, causing it to "pile up" toward shore. This storm surge can create a temporary rise in sea level which effectively carries the destructive wave forces even further inland, as well as inundating the lower coastal elevations. In 1969, Hurricane Camille caused a peak storm tide of more than 22 feet. If an extreme lunar tide were to occur simultaneously with this peak storm tide, the resulting destruction would be increased.

After spending several days flirting with the east coast, Hurricane Diana hit the North Carolina coast on September 13, 1984, with 110-mph winds and tides 10 feet above normal. Damage was estimated at more than $25 million even though the winds were of lower speed than for many hurricanes. As population increases on the coast, the cost of property damage increases for even relatively weak hurricanes.

In 1900, one of the most notable hurricanes in the history of the United States caused the drowning of 6,000 people in the vicinity of Galveston Island, Texas. Since then, modifications to costal structures and development of evacuation procedures have reduced the possibility that a similar tragedy will recur. After the hurricane, the elevation of the island was increased with fill, and a large seawall was constructed along much of the gulfward shoreline. In addition, a hurricane warning system was developed by the National Weather Service, National Oceanic and Atmospheric Administration. The system has markedly improved the ability of the National Hurricane Center to predict when a hurricane will reach land and to provide early warning to residents should evacuation be necessary.

Offsetting these technological advances is the greatly increased population density along many hundreds of miles of low-lying shoreline. Safely evacuating the increased population when a severe hurricane hits again will be much more difficult since more lead time is needed to avoid highway congestion and other problems.

A summary of the most costly United States hurricanes of this century shows that the losses in dollar values from the most recent severe hurricanes are much greater than those that occurred at the beginning of this century. This trend is due to the increase in property values and population shifts to the coast.

Sea Level Rise

A long-term general rise in sea level would expose the coastal zone to increasingly serious economic losses from winter storms and hurricanes. Some recent studies have projected that the general average sea level will rise at a faster rate than in the past (7). The studies predict that the increased carbon dioxide in the atmosphere, a result of the burning of fossil fuels, will create a "greenhouse" effect that will cause some melting of polar ice caps. The rise is estimated to be in the range of from 1 to 7 feet in the next century, whereas sea level rose approximately 1 foot during the last century. It is argued by some that natural mitigating effects will offset such a rise. However, if a long-term rise is in progress, there will be major problems on all of our low-lying coasts from strong storms. The most effective defense against such a possibility is informed planning based on sound data. A long-term measurement program should be initiated now to augment the efforts of the National Oceanographic Survey and other agencies to determine the magnitude and rate of sea level rise. Most existing tide gages are located in harbors for navigation purposes. A sea level measurement program should be planned and implemented to measure tides and mean sea level, not only in the harbors, but in the open ocean as well, over a long period of time. New measurement techniques will need to be developed as part of the research.

Ice and Other Cold Region Problems

The Arctic and the Great Lakes have attracted special attention lately because of the raw petroleum reserves in the former and the increased population and property values on the shores of the latter. Stationary ice can cause pull-out of piling for fixed structures, associated with very large horizontal loads. This pull-out results from tides and the wind and current forces acting on the ice. Ice

restricts navigation and, thus, the ability to conduct commerce in these regions. Coastal structures are threatened when ice scours the shoreline. A basic fund of knowledge about ice formation, the resulting forces on structures, the resulting shoreline scour, and ice mitigation measures is just beginning to form. Continued advances in our understanding of basic ice phenomena are essential for the development of modern engineering in arctic coastal regions.

Tsunamis

Tsunamis are long waves, usually generated in association with coastal earthquakes. Their character is such that as they approach land, the wave height increases drastically. Individual tsunamis have killed thousands of people in countries bordering the Pacific Ocean. In the United States more people have died in the past 50 years from tsunamis than directly from terrestrial earthquakes (8).

Other Marine Hazards

The marine environment, even when benign, creates difficulties for human operations because of our lack of basic knowledge. One example is the growth of sea organisms on structures. These organisms add to the size and roughness of structures, which in turn increases the forces of waves and currents on them. These growths also contribute to equipment failures by blocking intakes, coating heat exchangers, and causing instrument sensors to malfunction. More information is needed to be able to control or account for these organisms. Specifically, little is known regarding rates and characteristics of growths as related to geographical locations and depths below the surface. The effects of changes in water temperature, salinity, and nutrients from human activities need to be established.

The safety of moored ships, guyed offshore platforms, and oceanographic research buoys is sometimes limited by our knowledge of the resistance provided by sea floor sediments. Advances in geotechnical knowledge for terrestrial construction have been considerable in the past three decades. However, due in part to measurement problems and sampling difficulties and in part to the heterogeneous nature of marine sediments, advances in knowledge for marine construction have been slower. As activities and expenditures increase in the marine environment, we must learn more about the engineering characteristics of the geological features and geotechnical characteristics of the ocean bottom.

A Technology Deficit

Within the last 20 years, coastal and ocean engineering in the United States has steadily declined from a position of eminence in the world. The decline is a direct result of severely reduced funding of university research in this field. There is a feeling of alarm in this committee that the failure of the federal government to fund research, to support graduate students, and to modernize our laboratories has forced U.S. industries to import technology from the United Kingdom, the Netherlands, Japan, and Norway. The result, if this trend is not reversed, will be a continuing weakening of our present position and a worsening of our balance of payment deficits.

Hazard Mitigation Efforts and Research Needs

Engineering research must be encouraged in order to reduce the risk to the nation from marine hazards. The following efforts are recommended by the committee as the activities most needed at this time. Engineering research can generally be divided into three categories: field studies, laboratory studies, and analytical studies. However, social and economic research studies and engineering graduate teaching programs are also essential to the success of public works projects.

Field Studies

• Hazard assessment. More information about the physical and statistical anatomy of natural hazards such as winter storms, hurricanes, and tsunamis must be exposed. Long-term measurements of wind speeds, wave heights, and recurrence intervals typify the type of field measurements needed for each hazard. It is especially important to develop instruments and techniques to measure physical phenomena in the surf zone and the nearshore region during high energy events.

• Long-term studies. Most, if not all, studies to date have been short-term because of funding limitations. Long-term studies are needed to identify important slowly varying phenomena, such as the gradual change in mean sea level and the shifting of geological features. Expriments should be designed with completeness in mind; some projects may require several years of effort. In the past, budget restrictions have forced a tendency for projects to be short-lived and somewhat incomplete.

• Post event surveys. After severe events (such as tsunamis or hurricanes) that pertain to coastal and ocean engineering, there is a need for an immediate response by well-funded, well-equipped

engineers, who can record perishable data. For example, evidence on the actual extent of a tsunami is lost within a few weeks or months by the cleanup efforts of humans and the growth of vegetation.

• Prototype measurements. Accurate measurements of the response (stresses, motions) of seawalls, breakwaters, moored platforms, piers, pipeline ballast, and other structures to environmental forces are needed.

• Measurements of tide and long-term sea level rise. Measurements should be made in appropriate locations to obtain the information necessary for research on changes in relative sea level.

Laboratory Studies

• Generally, our university laboratories are not capable of performing important model studies for coastal and ocean structures. They lag far behind the size and quality of laboratories in Japan, Norway, the United Kingdom, the Netherlands, and other countries. They need to be upgraded with new wave basin and data processing equipment.

• Laboratory hydrodynamic model studies at present provide our only insight into the response of many engineering systems to certain marine hazards. Our ability to perform well is severely limited by antique equipment and inadequate space.

• The resistance characteristics of construction materials and configurations to the forces of the ocean need continuing research.

• Harbor siltation is an expensive phenomenon. Our ability to properly engineer for it by eliminating it or by preventive, or corrective, maintenance can be enhanced with appropriate laboratory model studies in coordination with analytical studies and field measurements.

Analytical Studies

• In the last three decades we have improved our ability to analyze the effects on structures of forces from the marine environment and the distribution and mixing of waste effluents by environmental forces such as wind, waves, currents, and earthquakes. We must continue to advance our ability to predict analytically, in order to reduce the human and material losses from marine hazards.

• The statistics (probabilities) of the combined effects of extreme events (high tides combined with strong winds from unfavorable directions, combined with land subsidence) needs to be studied.

Social and Economic Studies

• Alternatives to expensive protective works, such as long seawalls, must be considered by engineers. For example, the evacuation of an area threatened by a hurricane may be feasible and desirable. Such evacuations affect individuals through injuries, sometimes death, emotional distress, and lawsuits. These social costs must be considered along with monetary costs in designing coastal structures and in providing effective land-use planning.

Coastal and Ocean Engineering Graduate Programs

• University coastal and ocean engineering programs are usually at the graduate level (master's and doctoral degrees) because the technology required to engineer problems in the ocean and on the coast is heavily dependent on higher mathematics and advanced analysis methods. Some educators believe the number of graduates is adequate; however, most agree that the supply is less than the demand. Continuing education for practicing engineers is essential in this field because of the rapidly evolving technology. Design engineers must gain current knowledge through technical journals, monographs, books, and technical conferences—the end products of research. A national focus on research in this field will provide not only these end products, but an incentive for engineers to enter graduate schools and a means for faculty to contribute more effectively than ever to this discipline.

General Conclusions and Recommendations

Each year in the United States, natural and man-made hazards in our coastal and ocean environs cost many lives and sometimes billions of dollars in loss of property and commerce. These losses can be reduced through engineering research which produces better understanding of the hazards and better ways of dealing with the physical and economic results of severe events. This research carries national importance and should be accomplished within the aegis of a national agency that is relatively free of regulatory pressures and lobbies.

This ad hoc committee recommends that the National Science Foundation provide a special program on coastal and ocean engineering research. The program should be administered by the Civil and Environmental Engineering Division. The program should have its own panel of peers composed of professionals from the field of coastal and ocean engineering. The director of the program should be one of these professionals, to keep the program focused on the coastal and ocean engineering goals. He should

serve for two years, at which time the directorship should rotate to another panel member. This period will allow him time to assert his influence on the program, while not being too long to preclude his return to his own research.

The committee recommends a funding level of $3 million the first year, $6 million the second year, and steady funding of $10 million per year thereafter to provide much-needed research equipment, laboratory and field studies, and analytical research. Long-term funding levels can be best estimated after the first two-year period of activity.

Fig. 3. *On January 27, 1983, one of eight heavy storms impacted the California coast. The combined result of El Niño, high lunar tides, and the eight storms caused nearly $100 million worth of damage to coastal structures. The people in this photo are attempting to reinforce their beachfront cottage in Carlsbad, California.*

Benefits From Coastal and Ocean Engineering Research

Engineering research seeks to add to our knowledge of the physical world either for general, unspecified use or for solving a specific problem. Design engineers rely on this research to provide safe, yet economical facilities. If fundamental information is inadequate, engineers must rely on their judgment. When this happens, the possibility increases that the structure can be uneconomical, unsafe, or both. A distinguishing feature of coastal and ocean engineering is that there is less fundamental information from which to design than in terrestrial engineering. This dearth of information can be attributed to three factors: (1) the discipline is young; (2) marine structures require innovation; and (3) it takes time and money to develop proper hazard assessments. For example, the most prevalent hazard is ocean waves. Yet, wave measurements over an adequate number of years to establish reliably analytical probability distribution functions for the wave characteristics have not been conducted along any portion of the United States coastline. No data exist on high resolution directional wave spectra. Therefore, engineers must rely on judgment, and those with proven good judgment are in high demand. Designs of engineering works in the marine environment generally would be greatly enhanced by a dedicated, long-term program of wave measurements. Improved designs will benefit the country by reducing losses from storm waves.

Modern research in coastal engineering in the United States began in January 1929 with investigations into the cause of and remedy for erosion along the beaches of New Jersey under the direction of Prof. M.P. O'Brien, a member of his committee. This study led to the formation of the Beach Erosion Board of the U.S. Army Corps of Engineers in 1930, which became the Coastal Engineering Research Center (CERC) in 1963. CERC does excellent research for the U.S. military as well as for the civil sector; for example, the center conducts a modest wave measurement program. However, the activities at the center are too limited to meet the general needs of the profession, and a much broader scope of research is needed.

Research in coastal engineering increased significantly during the Second World War. The military sought a better understanding of wave generation by wind, together with the transformation of waves in the surf zone and the effects of the surf on landing craft, in order to plan and implement amphibious assaults on beaches. At present, fundamental knowledge is needed for the safe and economical development of offshore resources, for the protection and enhancement of the infrastructure along the shoreline, and for the increased safety and well-being of those who reside within the hazard zone of the coastal states, including those states bordering the Great Lakes.

There have been many successful applications of coastal and ocean engineering research in the United States and elsewhere. Because of the growing value of the infrastructure along the coast, the shifting of population density to and along the coast, and the rapidly increasing efforts to develop resources in greater water depths (with their more hostile environments), a much larger research effort will be required in the future if we are to reduce losses from natural hazards. The following two projects are illustrative of many successful engineering accomplishments that have benefited from effective research.

Miami Beach Nourishment Project

Miami Beach is a low barrier island that stretches for approximately 10 miles along the southeast Florida shoreline. Development of this island commenced in the 1930s and, at present, condominiums and large hotels are closely spaced along most of its length. In the late 1960s, the beaches had become so narrow from sand depletion that people in the tourist industry became concerned. The cause of the narrow beaches was threefold:

1) In an era (1940-1950) of little land use control, most of the beach front hotels expanded seaward, encroaching upon the beaches with swimming pools and sunning decks.
2) Natural erosion processes were gradually at work.
3) The construction of Baker's Haulover Inlet at the north end of Miami Beach interrupted the natural transport of sand into the system, inducing beach erosion.

Previous field, laboratory, and analytical studies had identified mechanisms for the littoral transport of sand by waves and the onshore/offshore sand transport on which the beach nourishment program was based.

The Miami Beach project included the relocation of 10 million cubic yards of offshore sand onto the beach, at an approximate cost of $65 million. The project is regarded as a success in

terms of reviving the ailing tourist industry, restoring the stability of the beach, and providing protection to the hotel foundations.

It is estimated that the increase in tourist revenue as a result of the project amounts to $20 million per year. The portion of the beach completed in September 1979 was subjected to Hurricane David, which it weathered very effectively. At present, the relatively minor expected erosion at the north end of the project has occurred because of the net southerly longshore sediment transport. The beach condition is nevertheless considered to be "excellent" over 98 percent of the project length.

Fixed Platforms in the Gulf of Mexico

The exploration for offshore petroleum resources in the Gulf of Mexico occurred gradually, commencing in the late 1940s. At that time, there was little information on soil conditions, wave conditions, currents, storm surges, and the associated wave forces to be expected during hurricanes. In addition, little was known about the effects of metal fatigue in a saltwater environment or the amount of biofouling to be expected. Substantial laboratory and field studies and advances in analysis have been undertaken to quantify the design environment, the fluid/structure interaction, and the structure response. As a result of this research, over 3000 platforms and thousands of miles of pipelines experience remarkably few failures in severe hurricanes. These platforms are designed for relatively shallow water and are rigid, composed as they are of stiff tubular members. Future construction will be in deeper water where rigid platforms may not be economical. Additional research will be needed to satisfy the special needs of deep-water structures.

Fig. 4. *A geodesic dome beach cottage at Nags Head, North Carolina, 1982. The beach erosion is clearly illustrated because the pilings supporting the cottage were originally driven into an area much like that in the right-hand side of the photo. The right-hand cottage does have a series of pilings equal to those shown by the left-hand cottage. In this case, at least 8 vertical feet of sand has been removed and the shoreline has recessed landward from 50 to 100 feet.*

Fig. 5. *Shore erosion and make-shift protection, 1973, Green Bay, Wisconsin*

Fig. 6. *Severe cliff erosion at Pacifica, California as a result of the unusual winter storms of 1982-1983. The Masonic lodge shown here was moved to another site as a result of this loss of foundation support.*

Natural Hazards: Overview and Recommendations

Coastal and ocean engineering, like terrestrial engineering, applies the laws of science to meet human development needs on the coasts and in the ocean. The coast, including estuaries, is considered to be the water-land interface. Engineering activities at this interface include beach protection, transportation across the interface, and recreation and commerce in the estuaries, all in balance with the preservation of important breeding grounds for ocean organisms. The ocean includes the continental shelf and deep-water regions removed from the land interface. Thus, the construction and design of offshore platforms and underwater pipelines and the solution of transportation problems in the sea are usually considered to be within the realm of ocean engineering.

Examples of coastal engineering are harbor designs, beach erosion, piers, harbor siltation, estuarine water quality as affected by dredge and fill projects and introduction of heat and municipal waste, breakwaters at entrances to harbors, and nearshore navigation in the presence of waves and crosscurrents. Other coastal engineering activities include constructing highways close to the shore, building beach homes and hotels, and designing sewers and systems for discharging power plant cooling water.

Examples of ocean engineering are the design, construction, and installation of offshore platforms and pipelines, offshore loading and off-loading terminals for super tankers, large oceanographic mooring arrays for research, submarine surveillance systems, moorings of large buoys and ships in the deep portions of the ocean, and artificial islands in the Arctic; the installation and maintenance of aids to navigation; the determination of the time distribution of pollutants discharged into the ocean; and the solving of towing problems.

Coastal and ocean engineering research is based on concepts of structural and fluid mechanics, materials engineering, geotechnical engineering, and construction engineering. Sometimes this engineering involves the weather; when it does, the work interfaces with that of atmospheric scientists as well as with oceanographers. Coastal and ocean engineering is intricately involved with

wave and current actions and the response of various kinds of systems (structures, sediments, wastes) to them. Ocean currents, tides, storm surges, earthquakes and associated tsunami waves, and the support capacity of bottom sediments are of concern in establishing structures and in other human activities (for example, recreational areas).

The committee considers the following topics to be of prime importance at the start of a national program in coastal and ocean engineering research.

Winter Storms and Hurricanes

The unusually severe destruction caused by waves along the California coast in the 1982-1983 winter storms was due to a combination of factors, including the storm route, size, position, and intensity (Figure 7). The storms caused much damage to the shoreline, as reviewed in the Executive Summary. Nearly $100 million worth of damage to public property was reported, as summarized in Table 1.

Severe storms also generate very large waves in the deep ocean that may or may not be breaking. Large, deep-water breaking waves can be particularly destructive to ships, boats, and oceanographic research buoys. Figure 10 is a photo of a large wave in the North Sea impacting on part of the Ekofisk oil production platform in Norwegian waters. Very little is known about the magnitude of forces from such breaking waves on platforms and coastal structures. Although the majority of platforms are constructed by petroleum companies, federal agencies also have used fixed platforms for radar stations, navigation, and military training operations. Federal agencies also have plans to deploy moored semisubmersible and other types of instrumented platforms. In addition, the U.S. Geological Survey is responsible for certifying industrial offshore platforms. Consequently, there is an urgent need for nonproprietary design data on breaking and nonbreaking wave forces on fixed and moored platforms, the effects of waves superimposed on currents, and the correlation and influence of combined waves and wind.

Hurricanes are cyclonic storms that form in the tropics and propagate to more northern latitudes. Winds take on energy from the relatively warm sea, and so they are high by the time they reach land. Hurricane Alicia struck Texas in 1983 with average wind speeds of about 120 mph and gusts up to approximately 150 mph. Very large waves were generated by these intense winds. This storm cost Texas more than $1 billion.

A summary of the cost of damages from the worst hurricanes since 1926 is given in Table 2. The hurricanes are ranked by cost,

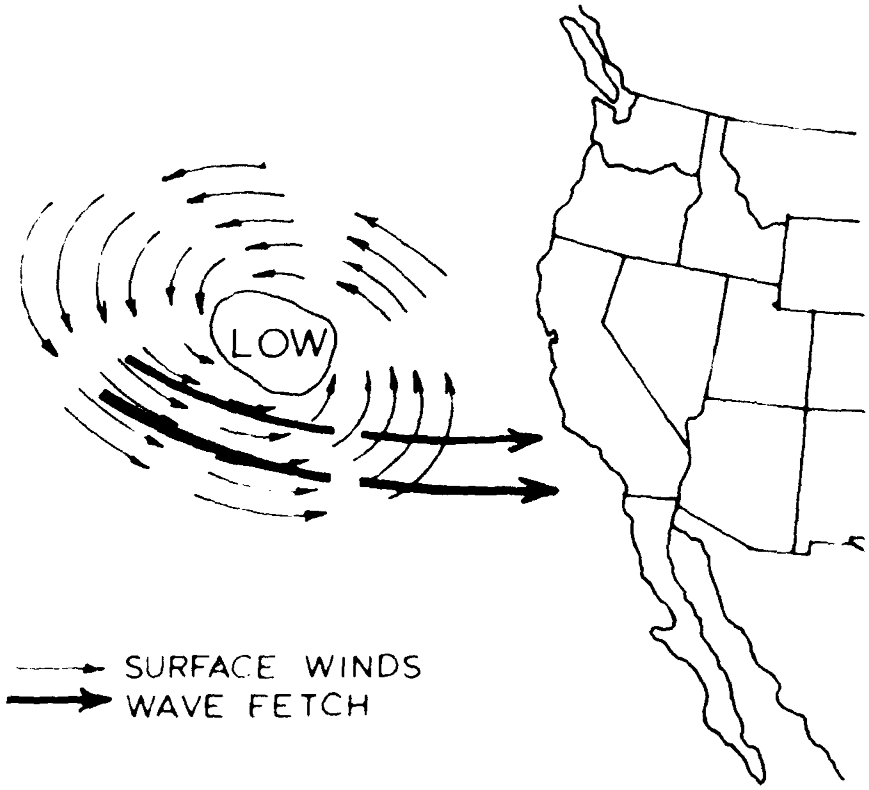


Fig. 7. *Conceptual view of the winds in a typically large winter storm of 1983 in the Pacific Ocean. The wave fetch was much further south and was nearly directly from the west instead of the usual northwest direction. El Niño also produced a 1-foot increase in mean sea level, which increased damage from waves considerably.*

not chronology, but there is a clear trend in the cost of damages: it is increasing with time.

In August 1984, a specialty conference was held in Galveston, Texas, by the American Society of Civil Engineers entitled, "Alicia One Year Later." It is significant that none of the 30 papers presented dealt with waves and their destructive forces. Most engineering efforts have focused on the wind speeds and the effects on terrestrial buildings. However, in addition to information on winds, coastal and ocean engineers require the wave and sea level conditions in such hurricanes. Wave measurement system installations must be designed to survive the wave conditions they are meant to measure. Long-term wave gage installations are called for at a number of locations along the continental shelf of the United States to form the statistical data base required for addressing exteme waves.

Table 1. Summary of Findings on Coastal Damage (2)

The coastal damage suffered in California affected harbor structures, piers, highways, park facilities, seawalls, private buildings, and vegetation. The losses included coastal flooding damage caused by elevated sea level and the costs of massive debris removal. Only 2 out of 15 coastal counties reported no damage. Predictably, the highest costs occurred in counties with the highest coastal populations.

The estimates of total damage by county, from north to south, are

	(Millions of $)
Del Norte	4.61
Humboldt	2.62
Mendocino	none
Sonoma	none
Marin	2.32
San Francisco	11.16
San Mateo	1.93
Santa Cruz	9.09
Monterey	3.39
San Luis Obispo	3.85
Santa Barbara	2.66
Ventura	1.57
Los Angeles	20.00
Orange	16.19
San Diego	13.56

The totals for the whole state, by category, are

	(Millions of $)
Beach facilities	12.17
Harbor facilities	18.84
Piers	10.42
Other facilities	51.52
STATE TOTAL	92.95

Table 2. Costliest Hurricanes, United States 1900-1983**
(more than $50 million damage)

	Hurricane	Year	Category	Damage (U.S.) Contemporary $ (millions)	1984 $ (millions)***
1.	FREDERIC (Alabama, Miss.)	1979	3	2,300	3,520
2.	AGNES (Northeast U.S.)	1972	1	2,100	5,300
3.	CAMILLE (Miss., La.)	1969	5	1,420	4,230
4.	BETSY (Fla., La.)	1965	3	1,420	4,750
5.	ALICIA (Texas)	1983	3	1,200	1,280
6.	DIANE (Northeast U.S.)	1955	1	831	3,200
7.	ELOISE (Northeast Fla.)	1975	3	550#	1,100
8.	CAROL (Northeast U.S.)	1954	3*	461	1,800
9.	CELIA (S. Texas)	1970	3	453	1,280
10.	CARLA (Texas)	1961	4	408	1,430
11.	CLAUDETTE	1979	T.S.§	400	613
12.	DONNA (Fla., Eastern U.S.)	1960	4	387	1,400
13.	DAVID	1979	2	320	490
14.	New England	1938	3*	306	2,200
15.	ALLEN	1980	3	300	410
16.	HAZEL (S.C., N.C.)	1954	4*	281	1,100
17.	DORA (Northeast Fla.)	1964	2	250	850
18.	IWA (Hawaii)	1982	1	234	260
19.	BEULAH (S. Texas)	1967	3	200	640
20.	AUDREY (La., Tex.)	1957	4	150	570
21.	CARMEN (Louisiana)	1974	3	150	340
22.	CLEO (Southeast Fla.)	1964	2	128	440
23.	HILDA (Louisiana)	1964	3	125	420
24.	Florida (Miami)	1926	4	112	660
25.	Southeast Fla., La.-Miss.	1947	4	110	580
26.	Northeast U.S.	1944	3*	100	600
27.	BELLE (Northeast U.S.)	1976	1	100	190
28.	IONE (N. Carolina)	1955	3	88	340
29.	Southwest and N.E. Fla.	1944	3	63	380
30.	Southeast Florida	1945	3	60	350
31.	Southeast Florida	1949	3	52	220

* Moving more than 30 miles per hour

\# Includes $60,000,000 in Puerto Rico

§ Only of Tropical Storm Intensity, but included because of high damage figure

** This information was taken from Ref. (6) with additional information from Dr. Frank Tsai (see committee members)

*** Cost for 1984 based on CPI national yearly average as the inflation rate

Fig. 8. *Undermining of foundation and building offset from Hurricane Eloise, 1975, Florida.*

Fig. 9. *Detail of inadequate construction details between foundation beam and piling. Erosion of supporting sand from under the beam in Hurricane Eloise, 1975, Florida.*

Almost no data exist for conditions within and adjacent to the surf zone during extreme events. Information is needed on wave characteristics, littoral currents, suspended sediment, and the distribution of sediment transport. This information should be interpreted in terms of the associated incident waves and currents.

Offshore Platforms

The combination of high waves and storm surge poses a serious threat to construction along the coasts and offshore. The Gulf of Mexico contains about 3000 platforms and thousands of miles of pipelines for the transportation of raw petroleum. Water depths range from only a few feet to 1025 feet (at the Shell Cognac platform). Offshore structures have been designed well with conservative methods, so that losses from hurricanes have been relatively small.

The few failures that have occurred in the last few years have been dramatic. Among the most notable failures of floating and bottom-mounted platforms was the *Alexander L. Kielland,* which capsized in a strong winter storm in March 1980 in the North Sea off the coast of Norway. The accident took 183 lives. This disaster

was directly caused by metal fatigue in a fillet weld for a hydrophone. A chain of events followed the failure of the weldment: some braces sequentially broke, followed by the collapse of one of five support pontoons and by severe listing with only a few minutes for escape before the giant platform capsized (10). Another disaster occurred when the *Ocean Ranger*, a semisubmersible drilling rig in the North Atlantic off New Foundland, capsized in a storm with the loss of 84 lives. Yet another was the drilling vessel *Glomar Java Sea*, which was lost along with the entire crew of 81 in October 1983 during a heavy storm in the South China Sea.

Fixed and moored instrumentation platforms are planned for use by federal agencies. Waves like the one in Figure 10 pose a real threat to platform safety. Future platforms are being designed and constructed for water depths of several thousand feet. Such platforms are very costly, so an overly conservative design can be needlessly wasteful. However, safety must be maintained. Therefore, more detailed information is needed on the influence of high winds, large waves, and the accumulation of marine biofouling on the structures. These natural phenomena result in large wave forces that must be resisted adequately by the structure. Research is called for not only to quantify and predict the accuracy of severe natural events but also to improve the reliability of structural designs using modern materials.

The foundations for these structures rest on submerged materials that behave much differently than their counterparts on "dry" land. This is a new area of study, sometimes called marine geotechnique, that requires a great deal of research.

Shoreline Erosion

Shoreline erosion represents a threat to lives and to much of the expensive infrastructure along the nation's shores. A 1971 assessment by the Corps of Engineers indicated that of the 35,000 miles of shoreline in the continental United States, over 200 miles were termed "critical" in terms of erosion potential. This means that some people living along the shoreline are in imminent danger of loss of life or property (12). Estimated remedial costs for 2700 miles of shoreline needing protective structures were, at that time, $1.8 billion. Today, the costs are much higher, partly because of the relatively small expenditures for beach protection that have been made since 1971, but also because of the large influx of populations to coastal areas and the resulting increased construction costs and property values.

Beach erosion can also be the result of man-made alterations to the natural environment. The sand supply to beaches can be reduced by the construction of dams on rivers that supply the

Fig. 10. *Winter storms and hurricanes cause huge waves to impinge on offshore platforms of many types. Here a large breaking wave impinges on a portion of the Ekofisk platform in the North Sea, off the coast of Norway.*

sand. Construction of, or improvements to, jetties at harbor channel entrances, and channel deepening, can cause sand erosion on one side of the jetties and sand deposition on the other. One example is Ocean City Inlet, Maryland, which was established by a hurricane in 1933 and stabilized by jetties. The shoreline to the north has accreted some 800 feet, and Assateague Island to the south has receded by some 1700 feet. At the time of construction, the magnitude of both accretion and erosion could not be predicted.

What little research has been done on this topic since then has yielded information that allows us to make at least approximate estimates of sand quantities. Further research is needed before we can apply this computation to improved future construction.

Beach erosion can be characterized by long periods of relatively little loss or even some accretion. However, during intense storms accompanied by high storm surge and large waves, the shoreline can recede by as much as 200 to 300 feet with the lowering of the nearshore profile by as much as 6 to 8 feet.

These storms create the greatest potential for destruction of upland structures. Most of the sand removed from the dry beach is transported seaward and deposited as an offshore bar during a 6- to 12-hour period. The recovery of the beach profile can be a much slower process, in some cases requiring up to five or more years for beaches to return to their prestorm condition. However, in Monterey Bay, where a small storm surge was associated with the 1982-1983 storms, severe erosion was replaced in one year. Research is needed to identify more clearly those conditions that result in long-term erosion.

Research can enable us to determine with more certainty the best course of action to be taken for protection of sensitive coastlines. In some cases a structure may be needed. In others planners should consider beach replenishment or zoning to prevent construction in hazardous areas.

Gradual erosion has placed considerable stress on the nation's beaches. In many locations, these beaches are extremely valuable recreational features as well as effective absorbers of high energy waves. Realistically, there are only three possible responses to this erosional stress: (1) armor the shoreline, in which case the beaches will gradually disappear as a result of the continuing erosion pressure; (2) nourish the beaches, a fairly expensive, but in some cases effective, approach; or (3) abandon any existing facilities on the shoreline and prevent future construction. The best solution obviously depends on the location and the associated economics; however, present knowledge and data bases are inadequate to make these decisions with confidence in many locations of concern. This knowledge gap is reflected in the present differences and discussions between the egineering and geological communities.

Capsizing

The Pacific Northwest fishing fleet is subject to considerable loss from winter storms. The storms can be sufficiently severe to keep fishermen in their harbors. However, if a ship is caught at sea in a severe storm with a fairly full hold, it may capsize, with a loss of lives and equipment. The average annual loss for the Pacific

Fig. 11. *Undermining of foundation followed by wall collapse. North Atlantic Storm, February 1973, Kitty Hawk, North Carolina.*

Northwest fishing fleet is 30 to 40 lives and $50 million in property (fishing boats). Recent research has shown that capsizings are caused mostly by a large quantity of free water on deck carried over the rail by large waves (13). A resonance can occur between the sloshing of the deck water and the roll period of the boat. The resonance, coupled with a particularly large wave and a full hold, can finally capsize the boat. This danger can be reduced with more research to determine a quantitative measure of how full the hold should be with respect to the occurring storm hazard, a better design of the ship rails and surface drainage, and a more stable boat design that reduces resonant rolling.

Recommendations

1. Research should continue to explore analytical and experimental means of determining more thoroughly the wave, current, and wind forces on ocean structures of various kinds.

2. Almost no data are available within the surf zone and just seaward of it on waves, currents, suspended sediment, sediment transport, and bathymetric changes during extreme events. Thus, we observe beach and dune erosion and damage to coastal structures, but we have almost no measurements of the physical phenomena causing the damage *when* it is occurring. Basically, this is because it is very difficult to take measurements during high-energy storms. Equipment and techniques must be developed to do this in conjunction with an intensive research effort to study the phenomena.

3. A research effort focused on the causes of beach erosion and methods for stabilizing beaches should be promoted by the National Science Foundation. It is true that many studies on this subject have been made by universities in the past and many others are at present underway by the U.S. Army Corps of Engineers and other agencies. However, the subject is so difficult and so broad that only a concerted, continuing effort will uncover the laws of nature, and, in doing so, yield better information for engineering design.

4. The causes and extent of structural fatigue in the marine environment should be investigated with the goal of identifying limitations of existing materials and developing improved materials for the special marine environment.

5. The engineering properties of marine geological rock and sediments should be more thoroughly explored for their efficacy as foundation materials for supporting vertical downward and upward direct loads and lateral anchoring loads.

6. The United States is in critical need of improved laboratory facilities for model studies. At least one large rectangular

wave basin with directional wave generation capability is required. This facility should be available for use by researchers from any university. Among the relatively large model studies that could be undertaken in the laboratory are those of sand transport processes on our beaches, harbor designs (including siltation characteristics), ship and platform responses to directional wave spectra, and the mechanics of short- and long-crested waves. The wave facility should be capable of producing deep-water breaking waves for studies of vessel stability under storm wave conditions.

Long-Term Sea Level Rise

Many scientists believe that the carbon dioxide and other gases in the atmosphere are increasing significantly because of the continued increase in the burning of fossil fuels and because of other human activities. Two studies by the National Academy of Science have predicted an increase of from 2 to 8 degrees Fahrenheit in average world-wide temperatures over the next century. Even a small general increase in the average annual temperature will cause increased melting of the large polar ice caps, a thermal expansion of oceanic waters, and a subsequent increase in the general sea level (7). (Some scientists think there are compensating mechanisms that will nullify such a trend.) The predicted sea level increase ranges from 1 foot to about 7 feet by the year 2100. Another recently completed report by the National Research Council predicts a probable upper limit of sea level rise of 2.3 feet during the next 100 years. (It is estimated that the total relative change between the sea level and the land during the last century has been 1 foot.) However, some scientists and engineers believe that the evidence is weak that a sea level rise is in progress. Their skepticism stems from the fact that virtually no accurate measurements exist on this subject.

If the predicted long-term sea level increases actually occur, the effects on the shorelines of the United States will be significant. The long-term horizontal shoreline recession may be from 100 to 300 times the relative vertical rise in sea level. These figures are substantiated by an approximate analysis of the change experienced along much of the sandy shoreline of the United States during the past century.

It is estimated that 50 percent of the population of the United States now resides within 50 miles of the coastline. A substantial portion of this area is low and relatively flat, such as the Mississippi River delta area and portions of the Texas and Florida coastlines. If we consider the addition of the storm surge and high lunar tides to a long-term sea level rise, it is obvious that major

dislocations of the population, with the associated loss of life and expense, will occur for each major hurricane or storm. This dangerous situation could be mitigated by the construction of dikes and other protective barriers similar to those constructed in the Netherlands. The costs would be significant, so the structures must be designed to keep both acquisition and maintenance costs to a minimum. To design structures that are both safe and economically sound, engineers rely heavily on good predictions of sea level rise, storm intensity, and storm track. Thus, it is urgent that a carefully organized program of measurements determine the current state of long-term sea level change along the coastlines.

Recommendation

Extended research for 10 years or more should be started as soon as possible to determine the long-term relative sea level with respect to the land masses of the United States. A plan should be developed and implemented to establish sea level indicators at sea and in other locations that will give the best information for this purpose. It is anticipated that sophisticated systems engineering will be required to establish the necessary base reference level. Instrumentation must be designed to survive severe storms. Remote sensing techniques may be helpful in reducing the amount of instrumentation required.

Tsunamis

A tsunami (commonly called a tidal wave) is a train of very long period waves usually generated by the impulsive motion of a part of the ocean floor which accompanies an earthquake. Tsunamis can also be caused by volcanic eruptions, landslides dropping into the ocean, and submarine slides. The waves are so long that their small height is unnoticeable in the deep ocean even though they travel through the deep ocean at speeds of from 250 to 500 mph. As these long period waves shoal onto the continental shelf and enter coastal waters, the energy is confined to a shallower depth and the wave height increases sharply, sometimes forming large destructive bores in very shallow water. Because of the offshore contours of the ocean floor, some areas—such as Coos Bay, Oregon; Crescent City, California; Anchorage, Alaska; and Hilo, Hawaii—act as focal points for the energy and are more sensitive to tsunamis than other areas. The casualties and damages from tsunamis in the United States since 1900 are summarized in Table 3.

We can anticipate and lessen the danger from tsunamis if we determine the relationships among ocean floor movement,

Table 3. Casualties and damage in the United States from tsunamis occurring since 1900.[a]

				Estimated Damage		U.S.
Year	Source	Dead	Injured	Contemporary $000	Equiv. 1984 $000[b]	Coasts With Damage
1906	S. America			5	50	Hawaii
1917	Samoa		--	[c]		American Samoa
1918	Kuril Is.	--		100	500	Hawaii
1918	Caribbean	40		250	1,200	Puerto Rico
1922	S. America		--	50	300	Hawaii, Calif., American Samoa
1923	Kamchatha	[d]	--	4,000	250,000	Hawaii
1933	Japan	--		200	1,900	Hawaii
1946	Aleutian Is.	173	163	25,000	130,000	Hawaii, Alaska, West Coast
1952	Kamchatha	--	--	1,200	4,000	Midway Is., Hawaii
1957	Aleutian Is.	--	--	4,000	14,000	Hawaii, West Coast
1960	S. America	61	282	25,500	85,000	Hawaii, West Coast, American Samoa
1964	Alaska	122[e]	200	104,000	350,000	Alaska, West Coast, Hawaii
1965	Aleutian Is.	--	--	10	30	Alaska
1975	Hawaii	2	--	1,500	2,700	Hawaii, West Coast

Note:

a) Data for 1975 tsunami from State of Hawaii Data Book, 1982, for other tsunamis from Ayres, Mileti, and Trainer, Univ. Colo. Inst. Behav. Sci. NSF-RA-E-75-005, 1975.

b) Adjusted from damages in 1957-58 $000 in Ayres *et al.* but not adjusted for increases in vulnerability.

c) Damage reported, but no estimates available.

d) Another source shows 116 dead and $4,000,000 damage, but these larger figures may include deaths and damage directly attributable to the accompanying earthquake.

e) Later estimated to be 119.

f) The last entry came from a). The rest of this table came from ref. (1).

wave characteristics, benthic dissipative mechanisms, and the destructive power of waves. Coastal effects such as the focusing of wave energy and the impingement of wave runup against coastal-sited structures are important. Large-scale model studies are needed to examine the characteristics of the changes in long waves as they propagate shoreward, where scale effects are minimized. As noted elsewhere in this report, a large wave basin is required in the United States where this modeling, including the investigation of three-dimensional effects, can be accomplished. Tsunami wave generation and propagation can, and should, also be studied analytically. Analytical methods that have been experimentally verified enable engineers to predict and design for extreme events. For example, a combination of analysis and model testing could perhaps yield a better computer program that will accept seismic signals from different origins, to provide a prediction of the probable magnitude and location of tsunamis at selected sites on the coast. Such studies could thus contribute to the development and implementation of an improved tsunami warning system.

Recommendations

1. Analytical and physical model studies should be undertaken to develop more reliable early warning systems for impending tsunamis.
2. Better coastal protective structures and means of identifying hazardous zones should be developed for coastal regions that are sensitive to tsunamis.
3. The magnitude of tsunami wave forces on structures needs to be determined for the design of tsunami-resistant structures.

Ice and Other Cold Region Hazards

The Arctic and the Great Lakes regions pose unique problems for coastal and ocean engineers because of ice forces and other cold region problems. Shorelines in cold regions are a mix of arctic tundra, sandy deposits, permafrost, and ice. These areas are also characterized by very high winds and cold temperatures. The buildup of ice ridges on beaches can be most severe, and where there is a relatively long-term increase in the water level, as has occurred in the Great Lakes, the destruction to the beach and coastal structures is exacerbated. During late spring meltdown, large ice chunks create a great deal of scour.

Because these problems have emerged only recently, the knowledge available for designs is minimal. Consequently, design criteria now in use tend to be very conservative, and they may sometimes result in overly expensive facilities. However, in some

Fig. 12. *Hurricane Frederic aftermath on the Alabama coast in September 1979. Wind and waves have nearly completely demolished this cottage by tearing off the roof, smashing out the windows, and removing the foundation materials from around the cottage, leaving it supported only by the pilings that were intended to be the foundation.*

Fig. 13. *Aftermath of the Alaskan tsunami of 1964.*

cases our lack of knowledge may make them unsafe. Too little is known, and research is urgently needed.

The force required to resist sea ice of maximum thickness (6 to 7 feet) is enormous, perhaps as large as 250,000 pounds per lineal foot. Much research on ice loads is needed, so that ice-resisting structures can be designed safely and economically.

A major problem arises when ice flows scrape the seabed in shallow water, gouging it by as much as 10 to 20 feet. To avoid damage from ice flows, pipelines need to be buried deeply in these scour areas. But engineers have to know the actual depth of gouging in order to prevent the unnecessary expense of burying the pipe too deeply.

Another unique cold weather problem occurs during spring breakup when river flows spread over the nearshore sea ice. As this fresh water drains through cracks and holes in the ice cover, vigorous whirlpools develop that can scour holes in the seabed with approximate diameters of 15 to 30 feet and depths of 10 to 20 feet. These craters in the seabed are termed "strudel scour." This phenomenon presents a significant hazard to any facility which might lie on or beneath the seabed. Little is known about the conditions which promote strudel scour, its frequency, or its intensity.

The Great Lakes have their own variations of sea coast problems. There are 10,000 miles of coastline, of which 3600 miles are in the United States. About 65 percent of the lake coastlines have suffered significant erosion in past years. Weather variations from year to year, a change in the mean water level, and the impact of mankind have caused the retreat of beaches and have posed problems to construction along those beaches. The increase in the water level has been a benefit to shipping, but a threat to the beaches. Siltation of marinas and ice damage to structures are major concerns.

Recommendation

It is recommended that more research be done on cold weather coastal and ocean engineering problems in the Arctic and the Great Lakes regions.

Other Marine Environment Problems

Coastal and ocean engineering addresses a diverse collection of problems. In a short report of this nature, it is possible to consider only those of major importance. This section includes some brief descriptions of additional subjects that have not received much publicity, but which, nevertheless, are of considerable significance.

Geological Hazards

Geological hazards are posed by relatively soft and unconsolidated sediments along portions of much of the continental shelf. The sediments constrain operations and construction of offshore facilities, affecting both cost and safety. Sometimes submarine mudflows of from 100 cubic yards to 250 cubic miles occur in a manner analogous to that of a landslide or side-slope stability failure on land. The time required for these sediments to achieve adequate engineering properties for foundations is estimated to be extremely long, and portions of the outer continental shelf are still undergoing active deposition. In this unstable state, the sediments respond to gravity, augmented by earthquakes, currents, waves, and other forces. The heterogeneous nature of marine sediments presents an unusually high degree of uncertainty in the design of marine foundations.

Better characterization of the engineering properties of these sediments and an improved understanding of the frequency of movement and failure are required to develop realistic designs.

Other marine geotechnique hazards include gassy sediments, turbidity currents, permafrost, and diaperism (in which the overlying sediments force the lower sediments upward through the upper layers).

Although the incidence of these failure mechanisms is fairly low, the consequences can be great, usually with no remedy except abandonment once a structure is in place and has experienced such problems. The Grand Banks slide of 1939 terminated service on a number of trans-Atlantic communication cables. The cables failed sequentially as the slide progressed toward the ocean floor, illustrating the magnitude and speed with which these phenomena can occur. Mudflows caused by Hurricane Camille (1969) led to the loss of two structures. In one of these cases, sediment displacement extended to a depth of some 70 feet below the bottom in a total water depth of 330 feet. Buried marine pipelines have "floated" out of their burial and were exposed to direct hydrodynamic forces. Bottom-laid marine pipelines have had sections suspended because of subsidence of the sediments.

Biofouling

Biofouling (the extensive growth of marine organisms on ocean structures) can increase the effective size of structures as well as their roughness. Both conditions cause a considerable increase in the hydrodynamic forces on the structure from waves and current. Marine organisms reduce the efficiency of cooling systems and the speed of naval and commercial ships. Older structures were (appropriately) designed quite conservatively. In

some cases the structures are cleaned of growth to reinstate their original geometric and hydrodynamic properties. We need to improve our capability to predict the degree of biofouling as a function of geographical location, elevation in the water column, and time. Knowledge of these variations is needed to build safely and economically, to establish safe and economical cleaning schedules, and to develop antifouling treatments.

Construction Materials and Techniques

Corrosion is an obvious hazard for construction materials. We need to know more about fatigue in the saltwater environment under normal and low temperatures.

Although considerable knowledge of corrosion and deterioration of materials in the marine environment has been gained, much remains to be learned. For example, it is reported that every year seamen are killed by the whiplash that occurs when a nylon towing rope (which can be up to 3 inches in diameter) breaks. Nylon is used extensively for the towing of barges and other objects because of its shock-absorbing capability. If stressed beyond the ultimate load, it breaks, releasing the energy stored by snapping back toward the towing craft and to the craft that is being towed. We need to know more about the relationship between the sea conditions, the towing speed, the towing resistance of various shaped vessels, the dynamics of tethers, and the long-term degradation of various materials that are used for towing lines.

Recommendations

1. Research should be emphasized on where and under what conditions submarine mudflows and other marine geotechnique hazards are likely to occur. The basic forcing mechanisms and how they trigger a failure should be examined, as should the basic transport mechanisms and internal stresses. The engineering properties and spatial distributions of marine sediments must be determined. Better analytical models that have been experimentally verified are urgently needed to estimate wave-structure-sediment interactions.

2. The extent of marine biofouling (geographical, depth, and time distributions) on structures in the oceans bordering the United States should be determined. Growth rates, types of organisms, and the ways in which both parameters influence forces on and operations of floating and fixed structures should be quantified.

3. Strength and fatigue characteristics of materials used in the ocean should be determined. In some cases, very nonlinear materials are used, and special analysis methods may be required to predict their response to the marine environment.

Research Needs

Loss of life and property, excessive maintenance, and biological damage can be mitigated with the knowledge obtained from engineering research. More and better information is needed in the following areas.

Hazard Reduction through University Engineering Research

University engineering research is the cutting edge of engineering graduate education. The U.S. must fund this research to sharpen the minds of its graduate students, to provide a stimulating environment for professional development of the faculty, and to provide the required information for designers and other practitioners that will reduce losses from natural hazards. The following areas are prime targets of university engineering research.

Common results of coastal or ocean engineering efforts are the acquisition of a facility in the ocean or on the coast, dredging, the protection of the water quality of the ocean or estuaries, and coastal zone management. Environmental studies are carried out in support of a design requiring locating, relocating, modifying, or terminating a structure or process such as the disposal of wastes in the ocean. Typical facilities include breakwaters, harbors, piers, offshore platforms, coastal roads, aids to navigation, beaches, outfall pipes, dikes, storm and tsunami barriers, oceanographic research buoys, and sensor platforms. The engineer attempts to predict the stresses within the structure, its motion, the fate of whatever that structure may contain, and the response of the surrounding environment to that structure or its contents. For example, ocean outfall pipelines are subjected to forces from waves, currents, mudflows, earthquakes, and construction loads. The engineer must design the outfall to resist these stresses while dispersing wastewater under severe environmental conditions. Furthermore, the facility must not unduly influence sand transport in the littoral region of the ocean, and the effluent must not unduly degrade the surrounding environment. All of these criteria must be met within a budget that is affordable.

Engineering predictions of the response of structures and the environment rely heavily on mathematics, tempered with the results of measurements and observations. This is particularly true in the case of ocean waves and currents. Very large and sometimes very compliant ocean structures are considered wherein the mathematical and statistical predictors are of an advanced and complicated nature. Therefore, to help mitigate the hazards of nature, we urgently need basic research into the nature of the mathematics and statistics for these predictors. Mathematical methods rely heavily on modern computers, laboratory and field measurements, and ingenuity in devising ever better methods of mathematical and statistical formulation.

The three basic areas of study for developing acceptable predictors for construction are (1) mathematics and statistics, (2) laboratory testing, and (3) prototype field measurements. Before engineers can have confidence in mathematical and statistical models, there must be carefully controlled experiments to test the theories.

The engineer can study a scaled model of an engineering project or the full-scale prototype. The advantages of working in the laboratory are that it is usually less costly, the physical variables can usually be controlled one at a time, the scaled prototype design conditions (design storm intensity, etc.) can be modeled, high-quality measurements can be made, and the test usually takes a relatively short time. Major disadvantages are that scaling effects sometimes limit application of the data to the full-scale prototype conditions, and analytical inferences must be used. Sometimes important phenomena cannot be included in a model study and the results must be interpreted knowingly. In addition, laboratories must be kept busy nearly full time to be self-supporting. Some countries, such as Japan, the Netherlands, and Norway, recognize the powerful advantages of large-scale laboratory experimentation. Those governments subsidize extremely high-quality laboratories. The payoff never enters a financial ledger, but it is real in terms of added safety and economy for coastal and ocean engineering facilities.

Laboratory model studies can add significantly to our knowledge of the response of engineering systems to marine hazards. Engineers in the United States, however, are severely constrained by the lack of quality facilities, which tend to be large and expensive. New funding is needed to establish them. Laboratory centers could be established which would be available to all users, regardless of the location of their employment. This cooperative venture would be similar to that existing now in the use of oceanographic research vessels.

The third area of investigation requisite to developing adequate predictors is field measurements. The principal advantages of field studies are that there are no scaling effects and all variables are necessarily included. The disadvantages of field studies are relatively high costs, lower reliability of measurements, the inability to control the variables individually by isolating the environmental parameters, and the risk of total loss of an experiment in an extreme environmental event. There are two categories of field studies—measurements of the response of a structural or fluid system to the various full-scale stimuli, and measurements of the stimuli themselves.

Long-term field measurements of storms and waves on all the coastlines of the U.S. are needed. A long-term commitment of at least 20 years should be made to gathering and preparing for fast retrieval the statistical information on wave parameters so that a proper assessment of that hazard can be made. The same is true for monitoring the general sea level. In fact, wave measurements and sea level measurements can possibly be combined.

Regardless of the care taken to design ocean structures properly, a very small fraction of the billions of dollars of construction per year will experience failure. Some of these may result in significant loss of life and costly property. Valuable information can be obtained from these failures, providing we accurately document the remaining evidence. For example, a tsunami may inundate a coastal area, drowning a number of people and destroying considerable property. A very basic question in such an incident is, how far inland did the wave travel? The answer to this question exists clearly for only a brief period of time before vegetation and human activities reduce the evidence. Similarly, evidence may be short-lived regarding the cause of the capsizing of semisubmersible drilling platforms or fishing vessels.

Recommendations

1. To ensure that valuable information is gathered and recorded after a disastrous event, we recommend that a team of experts be on call and a fund of money be available to dispatch this team to the site as soon as possible. Organized evaluations of coastal and ocean disasters are not now widely undertaken because neither the manpower nor the funds exist. The need for such studies is nationwide. Therefore, a federally funded program of this nature would be appropriate.
2. Long-term field measurements should be funded to study coastal and ocean hazards.
3. Field studies of full-scale prototype structures, where scale effects are nullified, should be encouraged.

4. Laboratory equipment should be revitalized and enlarged. Model studies are essential links in the three areas (analysis, model studies, and full-scale studies) of engineering research and we need to catch up with the capabilities of other nations.

5. Analytical studies based on mathematics, statistics, and computerized methods need to be enlarged to encompass the diverse range of activities in which the U.S. is involved on the coast and in the ocean.

Coastal and Ocean Engineering Education

Students of coastal and ocean engineering must have a thorough knowledge of fundamental and advanced mathematics and a rigorous, comprehensive understanding of the physics of water waves, tides, and currents. Beyond that, areas of specialization are in structural design and analysis, sediment transport, mixing processes, fluid and structure motion interaction, submerged soils and their characteristics as foundation materials, marine construction, and electronics. Complex water motions that result from the interaction of waves with fixed and moving stuctures and with bottom and shoreline sediments result in water motions and pressure distributions that are difficult to predict accurately. In addition, ocean waves often progress from different directions with complicated motions resulting from the several waves present. The emphasis on water waves in conjunction with the required broad technical background distinguishes a coastal or ocean engineer from other engineers. Because of the advanced nature of such studies, the degree earned is usually a master's or doctoral degree.

The analysis of coastal and ocean engineering structures is somewhat different from that of land-based structures, although advanced analysis techniques (for example, finite element analysis and thin shell methods) may be the same. The difference is in the type of structures. Fixed ocean platforms have been constructed, and additional structures are planned, that are taller than the Empire State Building. Large floating platforms supporting drilling equipment can be moored in water depths of a few thousand feet. Tension-leg platform decks can accommodate several football fields. Subsurface, moored, acoustic arrays for defense purposes may involve several thousands of feet of structural mooring.

Because of the complexity of the related phenomena, it is only at the graduate level that a student can acquire the necessary tools to be an effective coastal or ocean engineer. However, many coastal and ocean works are designed by engineers who have not had graduate training because the economics of our time induce them to enter industry right after receiving the baccalaureate.

Historically, coastal and ocean engineering has generated moderate interest among students, both from the United States and from other countries. However, in the past decade, starting salaries from private industry have steadily risen for graduates with a new bachelor's degree in engineering, while available funding for graduate students has declined because of federal budget cuts in programs that traditionally supported ocean-related engineering research. As a result, a trend has developed toward increased enrollment of foreign students and decreased enrollment of U.S. students in marine-related engineering programs.

In order to develop a technology that will mitigate losses from natural and human marine hazards, our universities must become economically competitive for the top engineering graduates so that a reasonable number will pursue graduate programs in this field. Not only will these young people help in the conduct of engineering research; they will also learn the basics of applied coastal and ocean engineering for later application to their profession. Well-trained students in this field historically have been in strong demand by marine-related industries, consulting firms, and government agencies. The number of U.S. graduates in this field can be increased by emphasizing a national program of research focused on coastal and ocean engineering.

In the last decade, a number of European, Australian, Indian, and Japanese laboratories have been built which have large experimental facilities with the most modern equipment, such as directional wave basins and long wave flumes. These superior facilities provide a technological advantage to foreign researchers because it is generally true that larger-model studies yield better test results. Because such laboratories usually attract talented personnel, they become centers of excellence with international reputations. Therefore, many U.S. industries conduct model tests for their advanced technology projects abroad. This potentially devastating trend can be reversed only with better equipment for research and graduate studies in universities in the United States.

Recommendation

A federal program should be implemented that will build the excellent facilities required to restore our universities to a position of eminence in coastal and ocean engineering. A large expansion in the financial support of research projects and graduate students is required to help mitigate the losses from natural hazards experienced by the U.S. on the coasts and at sea.

Social and Economic Studies

Engineers are required to design for both safety and economy. It is therefore natural that they become involved in planning for alternatives to expensive facilities, such as the evacuation of coastal lowlands prior to the arrival of a severe hurricane in lieu of designing hardened structures that will withstand any hurricane. Evacuation costs money, and we need to know the real cost in order to compare it to the increased costs of hardened facilities. A study of the economical and social concerns related to marine hazards is both reasonable and necessary.

Recommendation

The committee recommends that the coastal and ocean engineering program include both social and economic studies.

Programs Abroad

Countries with a strong emphasis on coastal and ocean engineering include Japan, Norway, the United Kingdom, the Netherlands, Germany, Denmark, Australia, and South Africa. Norway presents an interesting example. Prior to the discovery of the North Sea petroleum there was very little activity in Norway in coastal and ocean engineering except for work on fisheries problems and the design of shipping entrances. In the 15 or 20 years since the North Sea activity commenced, Norway, a country of 8 million people, has developed laboratory facilities far superior to those in the United States. Norway also has a visiting scientist program which attracts a number of coastal and ocean engineers from the United States. The primary facility in Norway is a large wave basin capable of generating directional waves. The basin is about 330 x 460 feet in the horizontal dimensions and 33 feet deep, with an adjustable floor allowing for different depths as needed. Similar basins of this general capability are at present being constructed in the United Kingdom, the Netherlands, Denmark, and Japan. United States petroleum companies operating in Norwegian waters are encouraged to sponsor studies in Norway. This incentive results in a flow of research funds from the United States to Norway, which increases even further Norway's general capabilities in coastal and ocean engineering. To at least some extent this results in a deterioration of the programs in the United States. This example illustrates the need for improved facilities in the United States as well as increased research to keep U.S. coastal and ocean engineers internationally competitive.

The situation in the Netherlands, the United Kingdom, Denmark, and Japan is similar to that in Norway except that the origins of coastal engineering in these countries predates the discovery of petroleum under the North Sea. To illustrate briefly the level of facilities and training within some of these countries, the Netherlands has recently constructed a large wave flume denoted as the "Delta flume" which is about 850 feet long, 17 feet wide, and 20 feet deep. This flume is capable of generating irregular waves that model ocean conditions up to heights of 8 to 9 feet, thereby representing prototype storm waves at scale ratios of from 1:3 to 1:8. This particular wave facility is large enough to minimize almost any concern about scale effects.

Both the Netherlands and Denmark are very competitive in attracting international projects for study in their facilities and in carrying out numerical modeling and analytical studies. Denmark in particular competes very effectively in carrying out field projects, particularly in developing countries. The results of these studies further enhance their laboratory and numerical modeling efforts.

The international education programs of the Netherlands generally last for one year and include a designated program in coastal engineering, which attracts many students from developing countries. These programs provide the Netherlands with an entree to the projects for these countries.

After WWII the United States was a world leader in coastal and ocean engineering. This lead has slipped during the last two decades because of a lack of competitive facilities and because of the greatly reduced research funding within the United States. To some extent, the lack of research funding is related to the funding by U.S. companies of research efforts overseas. To an even larger extent, our competitive edge is lost because of the very low level of funding by the United States government. At present there is no government program supporting coastal and ocean engineering in the universities.

The largest university wave flume is at Oregon State University (340 feet long, 12 feet wide, and 15 feet deep, and generating waves up to 5 feet high). This flume has been self-supporting since its construction in 1973. However, it is in need of new equipment, such as data recording and processing computers. Constructed with local funds, the OSU facility grew out of an intuition that it would be successful because of the scarcity of such installations in the United States and because of the keen interest of the ocean engineering faculty. This intuition proved to be sound. However, the activities in coastal and ocean engineering by the United States are so numerous that we need more and better installations, and

the facility at OSU is in need of improvements in order to compete with the major laboratories abroad. One of the first studies in this facility was for the government of the Netherlands. The Netherlands used the results and the experience to design the Delta flume, which now attracts many international research and engineering projects.

Conclusion

This quickly assembled report is intended as a preliminary planning document to show the importance of coastal and ocean engineering research in mitigating natural and man-made hazards on the coast and in the ocean. This report also intends to alert the reader to the fact that because of the lack of research funds, financial support of graduate students, and the nonexistence of funds to modernize U.S. university laboratories, domestic industries have been forced to import coastal and ocean engineering technology from abroad. If the National Science Foundation decides to direct funds to a program in coastal and ocean engineering, a more detailed cost summary will be developed by an appropriate committee of coastal and ocean engineers.

This report should be considered in conjunction with reference 9, the proceedings from a symposium at which an international group of engineers met and reported on research needs and facilities requirements from the viewpoint of shallow water ocean engineering. The group also discussed whether a national research center for this work should be established. However, this report emphasizes the cause and effect approach—that is, what are the research needs resulting from the existence of natural hazards?

Coastal and ocean engineering has evolved as a distinct branch of engineering because of the need to understand the marine environment in order to design the specialized structures required. Engineers spend a great deal of time studying the physics of wave motions and the response of structures and beaches to the waves. Special considerations have recently been directed toward the behavior of marine sediments as support for foundations.

There is a need to acquaint the public and governmental organizations in general with the discipline of coastal and ocean engineering and demonstrate that more well-educated practitioners are called for to carry out the research, design, construction, and operation of activities along our coastlines and at sea.

Recommendations

1. A research program should be identified within the NSF for coastal and ocean engineering research. A first-year budget of \$3 million is suggested to cover the costs of administration; analytical, laboratory, and modest field research studies; and planning studies for important new construction of research facilities. The second-year funding should be \$6 million to cover the same subjects as the first year's funding, plus a start on facilities improvements. The third and succeeding years should probably be \$10 million per year to supply funds for the accelerated research program and ongoing improvement of facilities. Reports that follow will more carefully break down costs into detailed areas.

2. The program should be administered by the Civil and Environmental Engineering Division of NSF. Peer review of proposals should be done predominantly, but not entirely, by coastal and ocean engineers. The director of the program should be a coastal and ocean engineer and serve in a two-year chairmanship, after which time another professional in the field should be selected.

3. Initially, the funded research should be directed toward hurricanes and winter storms, long-term sea level rise, tsunamis, ice and other phenomena characteristic of cold regions, biofouling and corrosion, and the ways in which these natural hazards influence beach erosion, breakwater stability, silting of harbors, wave forces on structures, flooding of low lands, capsizing of small vessels, loss of aids to navigation, ice abrasion in the Arctic, accumulation of biological growths on structures, and large submarine mudflows.

4. It is possible that a long-term sea level rise is in progress which will create severe losses within the next 100 years. It is imperative that we promote a concerted effort to make sophisticated measurements of mean sea level over the next 10-year period to identify changes in sea level.

The Committee

This ad hoc committee was selected to represent various areas of research work and various disciplines within the profession of coastal and ocean engineering. A balance was sought between eminent, well-established engineers and younger researchers in the early phases of their careers. These members come from a cross section of states concerned with coastal and ocean engineering. Some committee members represented administration and the field of science. The committee members are listed below with brief information on their backgrounds.

DAVID R. BASCO is a professor of civil and ocean engineering at Texas A & M University. Prior to that he worked at the Corps of Engineers Waterways Experiment Station in Vicksburg and spent some time in the Netherlands at the Delft Technical University and the International Institute of Hydraulic Engineering. His current research topics are coastal hydrodynamics, surf zone wave mechanics, wave breaking,and numerical simulation.

JOSEPH M. COLONELL is vice president of Woodward-Clyde Consultants and manager of their Alaska operations. Dr. Colonell has supervisory responsibility for Woodward-Clyde's engineering and environmental science practice in Alaska. His professional history includes academic and industrial research and practice in numerous diverse topics such as arctic coastal processes, fjord and estuarine hydrodynamics, beach and wave dynamics, physical oceanography, and seismic excitation of liquid storage tanks.

DOAK C. COX is director of the Environmental Center at the University of Hawaii. He received his B.S. degree from Hawaii in physics and mathematics and an M.A. and a Ph.D. from Harvard in geology. His experience is related to strategic minerals, Hawaii and Pacific water resources and geology, and environmental problems, including natural hazards. He is particuarly interested in tsunamis and tsunami hazards. His current work is in environmental research and service.

ROBERT A. DALRYMPLE is a professor in the Department of Civil Engineering at the University of Delaware. He received an A.B. at Dartmouth College in 1967; an M.S. at the University of Hawaii in 1968; and a Ph.D. at the University of Florida in 1973. He has been at Delaware since 1973. His research includes water wave mechanics and coastal engineering. He co-authored, with R.G. Dean, *Water Wave Mechanics for Engineers and Scientists*, published by Prentice-Hall in June 1984.

ROBERT G. DEAN is a professor of coastal and oceanographic engineering at the University of Florida. He holds B.S. and Sc.D. degrees in civil engineering from the University of California at Berkeley (1954) and the Massachusetts Institute of Technology (1959), respectively; and an M.S. in physical oceanography from Texas A & M University, 1956. His primary research interests are wave theories, wave forces on structures, coastal sediment transport, and the impact of storms on shoreline and coastal structures. He is a member of the Coastal Engineering Research Council, the Marine Board of the National Research Council, and the National Academy of Engineering. He is co-author of the book *Water Wave Mechanics for Engineers and Scientists* published by Prentice-Hall in June 1984.

ROB HOLMAN is an associate professor of oceanography at Oregon State University. He received his Ph.D. from Dalhousie University and has been at OSU since 1979. His primary research interest is nearshore processes.

ROBERT T. HUDSPETH is a professor of civil engineering in the Ocean Engineering Program at Oregon State University. He is a graduate of the U.S. Naval Academy and received an MSCE from the University of Washington and a Ph.D. from the University of Florida. His primary research interests are nonlinear, stochastic hydrodynamics and wave-structure-seabed interaction.

SCOTT A. JENKINS is an assistant research oceanographer at Scripps Institution of Oceanography, California. He received his Bachelor of Science degree from Yale University and a Ph.D. degree from Scripps Institution of Oceanography. His primary research interests are sedimentation control, beach erosion, wave driven streaming, and loading on structures.

GEORGE H. KELLER is dean of research at Oregon State University. He received an A.B. in geology at the University of Connecticut, an M.S. in geology at the University of Utah, and a Ph.D. in geology at the University of Illinois. He was associate dean in the School of Oceanography from 1975 to 1982 with an

interim period from 1976 to 1978 as the acting dean of the School. His research centers primarily around sediment mass physical properties and sediment dynamics in the deep-sea and continental margin areas.

JIIN JEN LEE has been a professor of civil engineering at the University of Southern California since 1970. Dr. Lee received his Ph.D. degree in 1969 from the California Institute of Technology. He has pioneered the "Boundary Integral Method" for use in analyzing the harbor response problem. Additional research work has been on linear and nonlinear wave propagation, wave-structure interactions, and the application of LDV for wave kinematics.

BERNARD LE MEHAUTE is a professor and chairman of ocean engineering at the Rosenstiel School of Marine and Atmospheric Science at the University of Miami since 1978. He was co-founder, director, senior vice president, and corporate chief engineer of Tetratech from 1966-1978. He received the International Coastal Engineering Award from the American Society of Civil Engineers in 1979; was a member of the National Sea Grant Review Panel from 1972-1978; and is a member of the Coastal Engineering Research Board. He is the author of the book *Hydrodynamics and Water Waves* and has over 100 publications.

WILLIAM G. McDOUGAL is an assistant professor of civil engineering in the Ocean Engineering Program at Oregon State University. Dr. McDougal received a B.S. in oceanography from Humboldt State University, California; in 1976; a B.S. in environmental engineering in 1976 at Humboldt State; an M.S. in civil engineering in 1979 at the University of Delaware; and a Ph.D. in civil engineering in 1982 at Oregon State University. His primary research topics are wave-soil-structure interaction, littoral processes, and groundwater modeling.

CHIANG C. MEI is a professor of civil engineering at the Massachusetts Institute of Technology. He received a B.S. from the National Taiwan University; an M.S. from Stanford University; and a Ph.D. from the California Institute of Technology. He is author of the book *Applied Dynamics of Ocean Surface Waves*. He has served as the first editor and is now the associate editor of the *International Journal of Applied Research*. His primary research interests are ocean wave dynamics, seabed dynamics, and subsidence of soils.

PETER L. MONKMEYER is a professor of civil and environmental engineering at the University of Wisconsin-Madison. He received B.S., M.S., and Ph.D. degrees from Cornell University. He

has held visiting positions at the River and Harbour Laboratory, University of Trondheim, Norway; and at the Institute for Coastal and Hydraulic Engineering, University of Hannover, Germany. His research interests include wave dynamics, wave forces on coastal structures, and the hydrodynamics of flow through porous media.

BRUCE J. MUGA is a professor of civil engineering at Duke University. He holds the B.S. degree in civil engineering from the University of Texas, and the M.S. and Ph.D. degrees from the University of Illinois. His main research interests are the behavior of moored-ship systems and marine terminals. He has served on numerous committees of the Waterways, Port, Coastal and Ocean Engineering Division of ASCE. He served as a member of the North Carolina Marine Science Council from 1970 to 1984 and at present serves on the Technical Advisory Committee for Marine Sanctuary Programs, National Oceanic and Atmospheric Administration, Department of Commerce. He co-authored the book *Dynamic Analysis of Ocean Structures*, contributed to the book *Dynamics of Offshore Structures*, and is author of many other papers and technical reports in the field of Ocean Engineering.

JOHN H. NATH is a professor of civil engineering in the Ocean Engineering Program at Oregon State University. He has B.S. and M.S. degrees from the University of Colorado (1952, 1960) and a Ph.D. degree from the Massachusetts Institute of Technology (1967). He designed the OSU Wave Research Laboratory and at present concentrates on wave forces on structures as influenced by biofouling, the response of moorings to waves, breaking waves in a random sea, and modeling techniques. He is a Fellow in the American Society of Civil Engineers and has been a registered Professional Engineer and part-time consultant since 1953. He has written over 80 technical papers and research reports on ocean engineering.

RONALD E. NECE is a professor of civil engineering at the University of Washington, where he received his BSCE in 1949. He received his MSCE at Lehigh University in 1951, and an Sc.D. at MIT in 1958. He has several society memberships including F.ASCE, M.ASME, and M.IAHR, and is a registered Professional Engineer. He has been a faculty member at the University of Washington since 1959, and since 1970 his research has included work on tidal flushing of small harbors, floating breakwaters, open channel flow, and models of hydraulic structures.

MORROUGH P. O'BRIEN is dean emeritus of the College of Engineering, University of California, Berkeley. He initiated research in coastal engineering in the United States in 1929 for the U.S. Army Corps of Engineers; he has been a member of the Beach Erosion Board and the Coastal Engineering Research Board from 1938 to 1980. During and following World War II, he carried out field and laboratory studies of amphibious operations for the U.S. Navy. He initiated the program of coastal studies at Berkeley in 1930. He is now adjunct professor in the Department of Coastal and Oceanographic Engineering at the University of Florida. He received the International Coastal Engineering Award of the American Society of Civil Engineers. He served as president of the American Shore and Beach Preservation Association from 1970 to 1984 and as chairman of the International Conference on Coastal Engineering from 1950 to 1978. He is a member of the National Academy of Engineering.

DAVID B. PRIOR is a professor in the Coastal Studies Institute at Louisiana State University. He received his B.A. in 1964 and his Ph.D. in 1968 at Queen's University, Belfast. He has engaged in mapping and identifying shelf and continental slope geology and offshore hazards, particularly in the northern Gulf of Mexico and in the Atlantic, under recent contracts with the USGS, BLM, and ONR and as a consultant to industry. He has published approximately 80 scientific papers. His primary research interests are marine geology, submarine slope instabilities, and various types of terrestrial landslides.

FREDRIC RAICHLEN is a professor of civil engineering at the California Institute of Technology, Pasadena. He received a B.E. from Johns Hopkins 1953 and an S.M. and Sc.D. from the Massachusetts Institute of Technology in 1955 and 1962, respectively. Primary research interests are wave dynamics and kinematics and tsunamis.

ROBERT L. SCHIFFMAN is a professor of civil engineering at the University of Colorado. His primary research interest is geotechnical engineering with an emphasis on marine geotechnology.

E. A. SILVA is Division Head of the Office of Naval Research Ocean Technology Program. He received a B.S. in metallurgical engineering from Stanford University; an M.S. in materials science from Stanford University; and a Ph.D. in naval architecture/ocean engineering from the University of California at Berkeley. He is a member of 13 professional societies and a registered Professional Engineer. He has 17 years experience in ocean engineering and 2 years in the aerospace industry.

FRANK Y. TSAI is the senior technical advisor in the Office of Risk Assessment, Federal Insurance Administration, Federal Emergency Management Agency. He has M.S. and Ph.D. degrees in civil engineering from the University of Minnesota. He is responsible for the development of coastal hazard study methodologies and was a member of the Barrier Island Task Force and Interagency Committee on Tsunamis and Flood Waves. For many panels and committees of the National Academy of Sciences, he served as Technical Liaison or Project Officer.

J. KIM VANDIVER is an associate professor at the Massachusetts Institute of Technology. He received a B.S. from Harvey Mudd College (1968) and M.S. and Ph.D. degrees from the Massachusetts Institute of Technology and Woods Hole Oceanographic Institution (1969 and 1975). His primary research interest is the dynamics of offshore structures.

ROBERT W. WHALIN is chief of the Coastal Engineering Research Center (CERC) at the USAE Waterways Experiment Station in Vicksburg, Mississippi. He has responsibility for an annual work load of about $15 million. CERC is responsible for all Corps of Engineers research and development and project-related investigations concerned with coastal/ocean engineering. He has authored and co-authored over 75 technical reports and publications.

ROBERT L. WIEGEL, is a professor of civil engineering at the University of California, Berkeley. His primary research interests are wave spectra, surf characteristics, wave forces, tsunamis, and mixing of densimetric discharges. He is chairman of the ASCE Coastal Engineering Research Council; a member of the U.S. Army Coastal Engineering Board; a former member of the National Research Council Marine Board; and a member of the National Academy of Engineering. Dr. Wiegel is author of the book *Oceanographical Engineering;* editor of the book *Earthquake Engineering* and the book *Directional Wave Spectra Applications;* and author of more than 100 papers and numerous technical reports on many aspects of coastal engineering and offshore engineering. Dr. Wiegel is also a consultant in the field.

References

1. Ayre, R. S., "Earthquake and Tsunami Hazards in the United States: A Research Assessment," Institute of Behavioral Sciences, University of Colorado, No. NSF-RA-E-75-005, 1975.

2. California Dept. of Navigation and Ocean Development, "Assessment and Atlas of Shoreline Erosion Along the California Coast," A Report by the State of California—The Resources Agency, Dept. of Navigation and Ocean Development, July 1977.

3. California Interdepartmental Agencies, "Coastal Storm Damage in 1983," A Task Force Report to the Secretary for Resources, Resources Agency, State of California Coastal Commission, Coastal Conservancy, Department of Conservation, Office of Emergency Services, and Department of Parks and Recreation, November 1, 1983.

4. Committee on Natural Disasters, National Research Council, "Storms, Floods and Debris Flows in Southern California and Arizona, 1978 and 1980," Proceedings of a Symposium at the Environmental Quality Laboratory, California Institute of Technology, September 17-18, 1980.

5. Dean, R. G., "Shoreline Erosion Due to Extreme Storms and Sea Level Rise," Coastal and Oceanographic Engineering Dept., University of Florida, Sea Grant Project R/T-24, December 1, 1983.

6. Federal Emergency Management Agency, "Preparing for Hurricane and Coastal Flooding: A Handbook for Local Officials," Office of Ocean and Coastal Research Management, U.S. Dept. of Commerce, NOAA, March 1983.

7. Herbert, P. J. and Taylor, G., "The Deadliest, Costliest and Most Intense United States Hurricanes of this Century," NOAA Technical Memorandum NWS NHC 7, August, 1978.

8. Hoffman, J. S., Keyes, D. and Titus, J. G., "Projecting Future Sea Level Rise—Methodology, Estimates to the Year 2100 and Research Needs," A Report of the Strategic Study Staff Office of Policy Analysis, Office of Policy Resource Management, U.S. Environmental Protection Agency, 2nd Edition Revised October 24, 1983.

9. Houston, J. R. and Tsai, F. Y., "Tsunami Hazards in Coastal Zones," Coastal Zone '83, Vol. III, Proceedings of the Third Symposium on Coastal and Ocean Management, American Society of Civil Engineers, San Diego, CA, June 1-4, 1983.

10. Lee, T. T., "Proceedings of the Workshop on Shallow Water Ocean Engineering Research—Research Needs and Facilities Requirements," Report for the National Science Foundation, Technical Report #56, U. Hawaii, Look Lab, 83-3, September 1983.

11. Moon, T., "The Alexander L. Kielland Accident," Proceedings from the first Robert Bruce Wallace lecture, Department of Ocean Engineering, Massachusetts Institute of Technology, June 1981.

12. Pryor, D. B. and Coleman, J. M., "Active Slides and Flow in Under-Consolidated Marine Sediments on the Slopes of the Mississippi Delta," *Marine Slides and Other Mass Movements*, ed. Svend Saxov and J. K. Nieuwenhuis, Plenum Publishing Corp., 1982.

13. U.S. Army Corps of Engineers, "Report on the National Shoreline Study," Department of the Army, Washington, D.C., August 1971.

14. Coglayan, I. H., "Effect of Water on Deck on the Motions and Stability of Small Ships," Ph.D. Thesis, University of Washington, Dept. of Mechanical Engineering, August 1983.

February 14-15, 1984
NSF/ONR Workshop Participants

Prof. David Basco
Dept. of Civil Engineering
Ocean Engineering Program
Texas A & M University
College Station, TX 77843
(409) 845-4568

Dr. J. M. Colonell
Woodward-Clyde Consultants
701 Sesame St.
Anchorage, AK 99503
(907) 561-1020

Dr. Doak Cox, Director
Environmental Center
University of Hawaii
2550 Campus Rd.
Honolulu, HI 96822
(808) 948-7361

Prof. R. A. Dalrymple
Dept. of Civil Engineering
University of Delaware
Newark, DE 19711
(302) 368-1709

Prof. Robert G. Dean
Dept. of Oceanographical and
Coastal Engineering
University of Florida
Gainesville, FL 32611
(904) 392-2416

Prof. Robert A. Holman
College of Oceanography
Oregon State University
Corvallis, OR 97331
(503) 754-2912

Prof. Robert T. Hudspeth
Dept. of Civil Engineering
Oregon State University
Corvallis, OR 97331
(503) 754-3631

Dr. Scott Jenkins
Shore Processing Laboratory, A-009
Scripps Institution of
Oceanography
University of California
La Jolla, CA 92093
(619) 452-6480

Prof. George H. Keller
Dean of Research
Oregon State University
Corvallis, OR 97331
(503) 754-3437

Prof. Bernard Le Mehaute
Ocean Engineering
University of Miami
4600 Rickenbacker Causeway
Miami, FL 33124
(305) 361-4636

Prof. Jiin-Jen Lee
Dept. of Civil Engineering
University of Southern California
Los Angeles, CA 90007
(213) 743-2941

Prof. William G. McDougal
Dept. of Civil Engineering
Oregon State University
Corvallis, OR 97331
(503) 754-3631

Prof. C. C. Mei
Dept. of Civil Engineering
MIT - Bldg. 48-413
Cambridge, MA 02139
(617) 253-2994

Prof. P. L. Monkmeyer
Dept. of Civil and Environmental
Engineering
University of Wisconsin-Madison
Madison, WI 53706
(608) 262-2471

Dr. Bruce J. Muga
Professor of Civil Engineering
Duke University
Durham, NC 27706
(919) 684-2434 Ext. 48

Prof. John H. Nath
Dept. of Civil Engineering
Oregon State University
Corvallis, OR 97331
(503) 754-2354

Prof. Ronald E. Nece
Dept. of Civil Engineering
University of Washington
Seattle, WA 98195
(206) 543-2531

Dr. Morrough P. O'Brien
P.O. Box 265
Cuernavaca
Morelos, Mexico 62000
011 (527) 312-0645

Dr. David Prior
Coastal Studies Institute
Louisiana State University
Baton Rouge, LA 70803
(504) 388-2396

Prof. Fred Raichlen
W. M. Keck Laboratory
California Institute of Technology
Pasadena, CA 91125
(213) 356-4403

Prof. Robert Schiffman
Dept. of Civil Engineering
University of Colorado
Campus Box 428
Boulder, CO 80309
(303) 492-7607
(Dept. Office Ext. 7315)

Dr. Eugene Silva
Office of Naval Research
Code 421
800 N. Quincy St.
Arlington, VA 22217
(202) 696-4358

Dr. Frank Tsai
Senior Technical Advisor
Federal Emergency Management Agency
Washington, D.C. 20472
(202) 382-0656

Prof. J. Kim Vandiver
Dept. of Ocean Engineering
MIT - Bldg. 5-222
Cambridge, MA 02139
(617) 253-4366

Prof. Robert L. Wiegel
Dept. of Civil Engineering
University of California
Berkeley, CA 94720
(415) 642-7340

Dr. Robert Whalin, Chief
Coastal Engineering Research Center
Waterways Experiment Station
P.O. Box 631
Vicksburg, MS 39180
(601) 634-2010